

B Physics at CDFII

XXXVIIIth Rencontres de Moriond

Electroweak Interactions and Unified Theories

March 15th-22nd, 2003 Les Arcs

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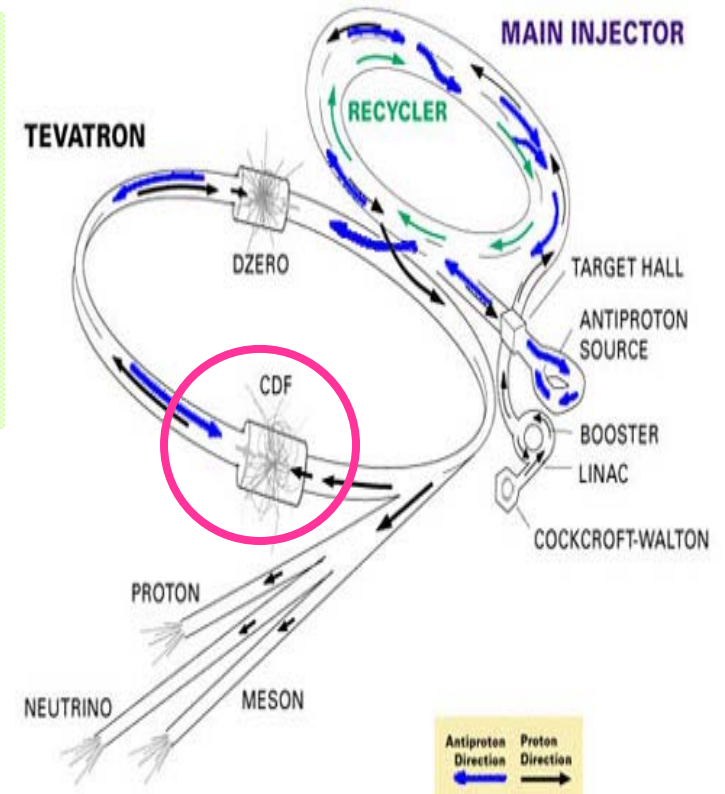
Scuola Normale Superiore & INFN - Pisa

for the CDFII Collaboration



Tevatron $p\bar{p}$ collider

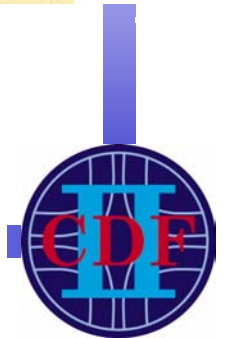
- ✓ **Main Injector**: injector optimizes \bar{p} production
- ✓ **Recycler**: store and cool \bar{p} (ready 2004)
- ✓ **Collision rate**: 396 ns crossing time
(36x36 bunches) $\rightarrow \sim 2M$ collisions per second
- ✓ **Center of Mass energy**: 1.96 TeV



Today: **record luminosity**: $3.7 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$
4 to 7 pb^{-1} /week delivered

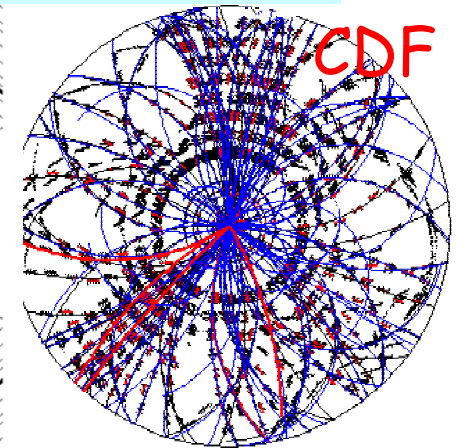
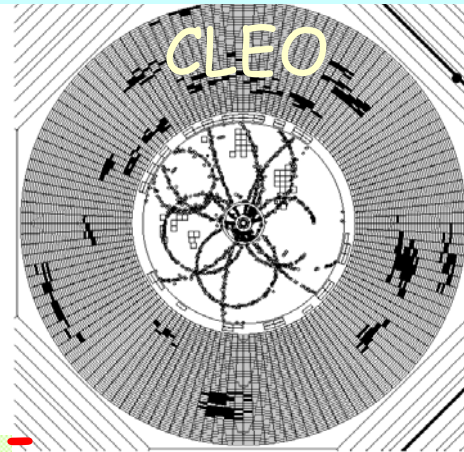
Goal: **inst. luminosity**: $O(1) \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
16 pb^{-1} /week delivered

Results of this talk based on $\int L dt \leq 70 \text{ pb}^{-1}$



B physics at $p\bar{p}$ collider

- ✓ x-section $b\bar{b}$ is $O(10^5)$ larger than $e^+e^- @ \Upsilon(4S)/Z^0$
- ✓ Open wide spectrum of B hadrons:
 $B^\pm, B^0, B_s, B_c, \Lambda_b, \Xi_b$



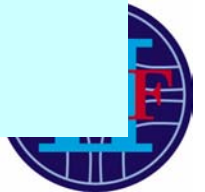
- Total inelastic x-section: $\sim 10^3 \times \sigma(b\bar{b})$
- BRs for interesting processes: $\sim O(10^{-6})$
 - S/B at production @ Tevatron is: $\sim 1/10^9$
 - S/B at production at B-factory $\sim 1/10^6$
- Mean multiplicity of tracks/event $\sim \times 4\Upsilon(4S)$
 - Combinatoric background
- Events pile-up within the same beam x-ing
 - Combinatoric background
 - Typical S/B at analysis level : $\sim O(0.5 \div 5)$

THE SOLUTION:

Vertex detector

+

Trigger



EM + HAD calor.

- **Central:** scintillat.
- **"Plug"**: tile-fiber

Muons:

- **Central:** $|\eta| < 1$
- **Fwd:** $1 < |\eta| < 1.6$

Trigger

2D-silicon tracks
at Level2

DISCRIMINATE

B events from
background
reconstructing a
decay vertex
displaced wrt the
point of primary
interaction

Time of flight

Scintil. PID (p,K, π)
100 ps @ 140 cm

Tracking: **Si strips** + **drift chamber** (in 1.4T)

- 3D-track, 7/8 layers, $|\eta| < 2$, $1.6 \text{ cm} < R < 28 \text{ cm}$
- 100 ns drift, $0.3 \text{ m} < R < 1.4 \text{ m}$, $\sigma(1/P_T) \sim 0.1\% \text{ GeV}^{-1}$, dE/dx info

B Triggers and data samples

Larger yield: lower Pt threshold wrt RunI: $e(\mu)$: 8 (2.2) \rightarrow 4 (1.5) GeV

Better S/N \rightarrow trigger on long-lived decays (displaced tracks)

Di-Muon (J/ψ)

$Pt(\mu) > 1.5 \text{ GeV}$

J/ψ modes down to
low $Pt(J/\psi)$ ($\sim 0 \text{ GeV}$)

- CP violation
- Masses, lifetimes
- Quarkonia, rare decays

Displaced trk + lepton (e, μ)

$IP(trk) > 120 \mu\text{m}$

$Pt(lepton) > 4 \text{ GeV}$

Semileptonic modes

- High statistics lifet.
- Sample for tagging studies

2-Track Trig.

$Pt(trk) > 2 \text{ GeV}$

$IP(trk) > 100 \mu\text{m}$

fully hadronic modes

- B_s mixing
- CP asymmetry in 2-body charmless decays

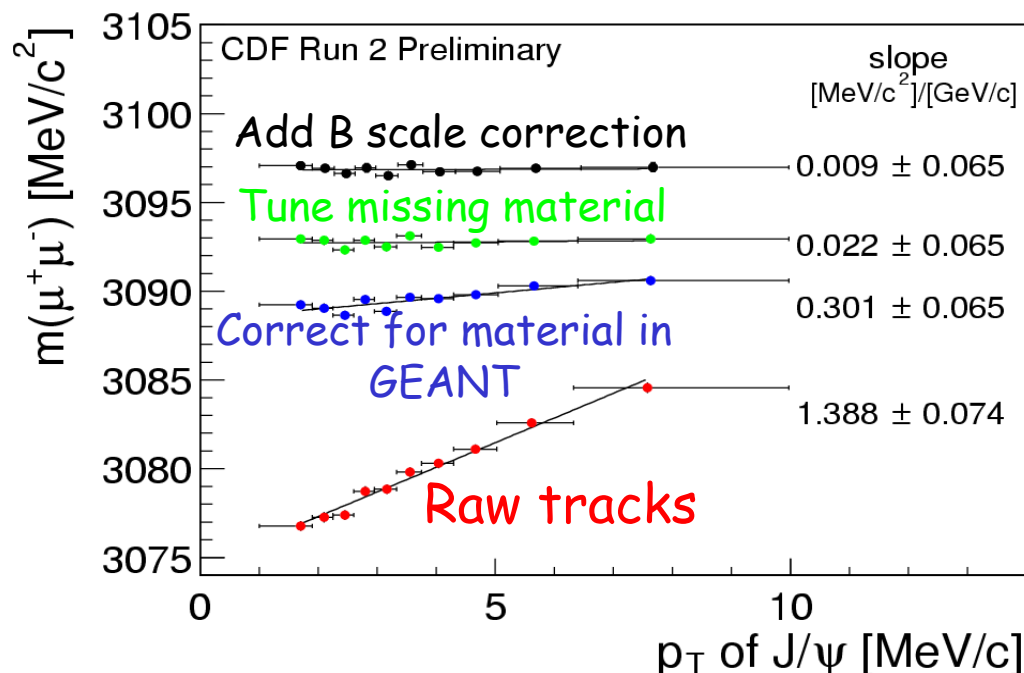


Detector calibration: \vec{p} scale & B-field correction

MASS SCALE: $M_{CDF} = M_{PDG} - \Delta M(P\uparrow)$

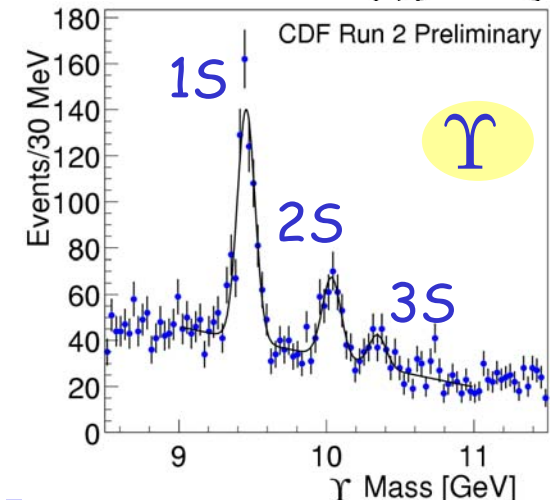
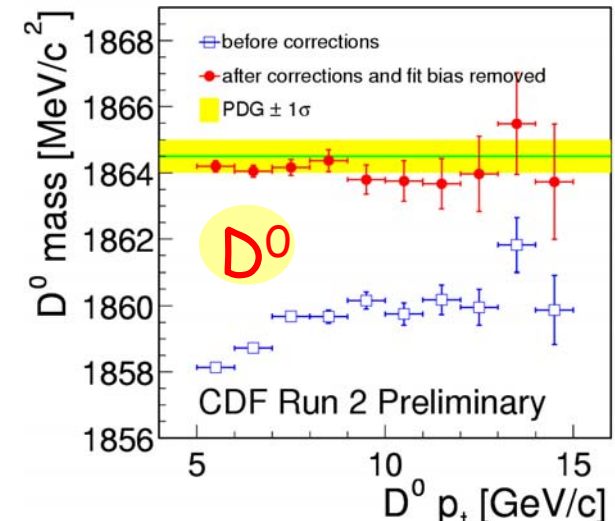
Use J/ψ to correct for B field and energy loss:

$\sigma(\text{scale})/\text{scale} \sim 0.02\%$



Sanity
check
with
known
signals:

D^0 and γ



Mass measurements

	CDF mass (only ~20 pb ⁻¹)	$\Delta_{\text{PDG}} / \sigma_{\text{CDF}}$
B^+	$5280.6 \pm 1.7 \pm 1.1$	0.8
B_d	$5279.81 \pm 1.9 \pm 1.4$	0.2
B_s	$5360.3 \pm 3.8 \pm \begin{smallmatrix} 2.1 \\ 2.9 \end{smallmatrix}$	-2.1
$\psi(2S)$	3686.43 ± 0.54	0.9

$M(B_s)$ is already the
second best in the
world (after CDF RunI)

$D_s^\pm - D^\pm$ mass difference

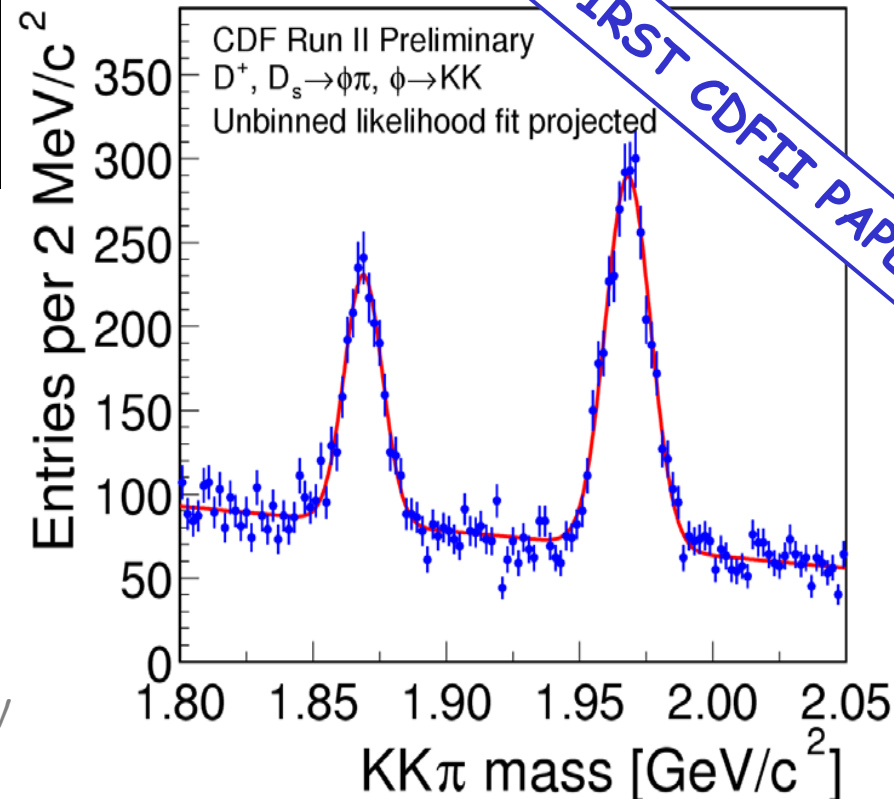
Both $D \rightarrow \phi \pi$ ($\phi \rightarrow KK$)

$\Delta m = 99.28 \pm 0.43 \pm 0.27 \text{ MeV}$

PDG: $99.2 \pm 0.5 \text{ MeV}$

(CLEO2, E691)

Systematics dominated by background modeling



Exclusive lifetime $B_s \rightarrow J/\psi \phi$

Probe of CDFII vertexing performance

Important for simultaneous measurement } $\frac{\tau(B_s)}{\tau(B_d)}$

Use control channels: $B_u \rightarrow J/\psi K^+$ and $B_d \rightarrow J/\psi K^{0*}$

Main systematics from alignment and resolution function

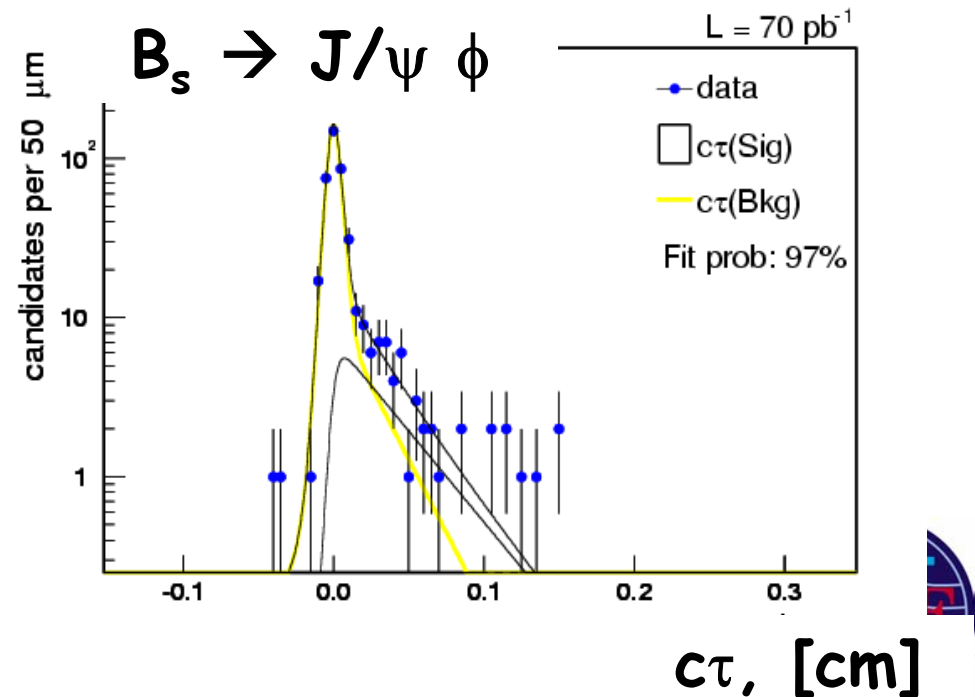
	Lifetime (ps)
B^+	$1.57 \pm 0.07 \pm 0.02$
B_d	$1.42 \pm 0.09 \pm 0.02$
B_s	$1.26 \pm 0.2 \pm 0.02$

Systemat.
& statist.
errors
already @
Run I level

$$\frac{\tau(B_s)}{\tau(B_d)} = 0.89 \pm 0.15$$

$$\frac{\tau(B^+)}{\tau(B_d)} = 1.11 \pm 0.09$$

DF - Moriond EW -



$B_s(1)$: from di-muon

$B_s \rightarrow J/\psi \phi \rightarrow [\mu\mu] [KK]$

ONLY @ Tevatron

- Weak phase of V_{ts} :

Time-dependent asymmetry in decay rates. (quick oscillat.)

Needs tagging

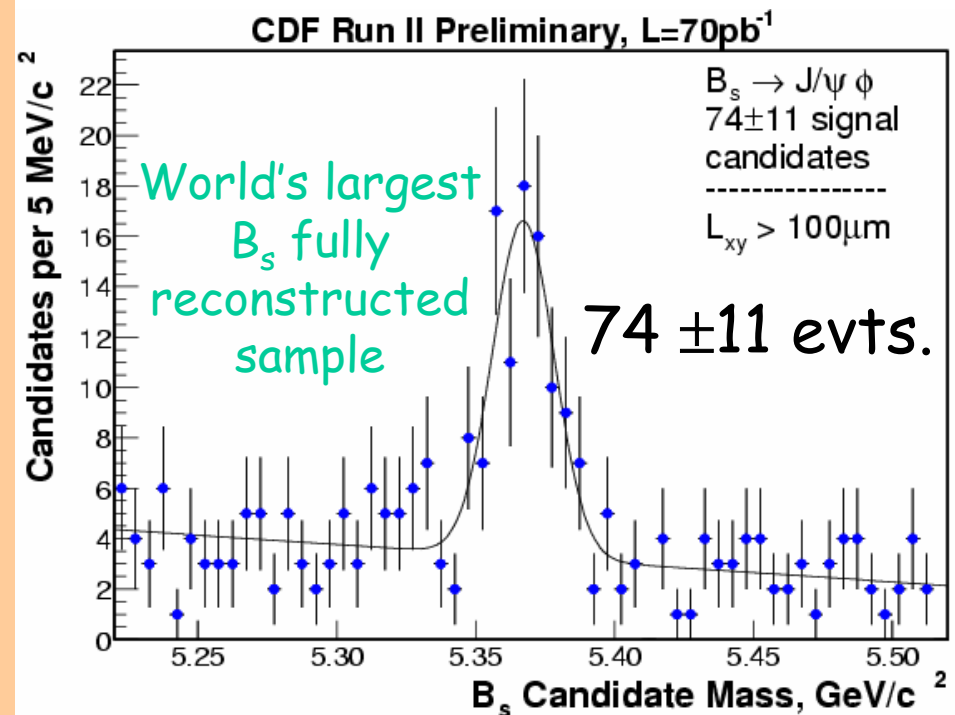
Mix of CP-odd/CP-even states

→ additional dilution

→ angular analysis required

- $\Delta\Gamma_s$:

Exclusive lifet + angular analysis



Yield/Lumi = 2 x RunI

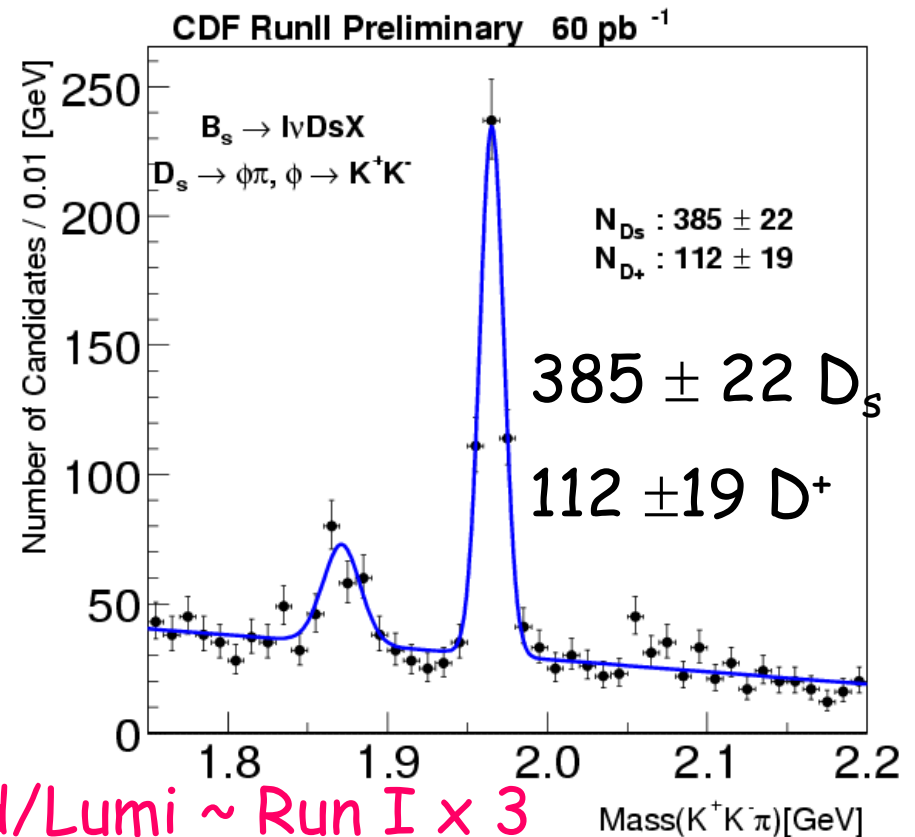
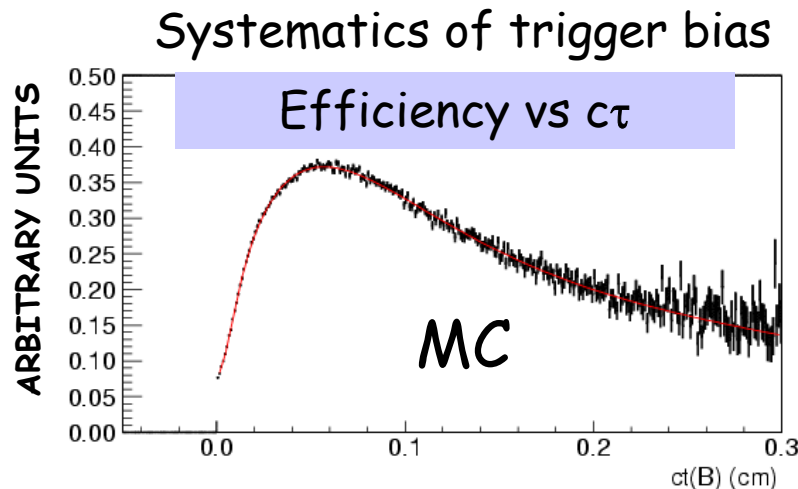
B_s (2): from: lepton + displaced track

$B_s \rightarrow D_s l \nu \rightarrow [\phi \pi] l \nu \rightarrow [[KK] \pi] l \nu$ ONLY @ Tevatron

HIGH STATISTICS SAMPLE:

- Inclusive lifetime: $\rightarrow \frac{\tau(B_s)}{\tau(B_d)}$
- Mixing (moderate x_s):

good S/N, limited time
resolution: back-up sample



Yield/Lumi ~ Run I x 3

S/N ~ Run I x 2

EW - March 03



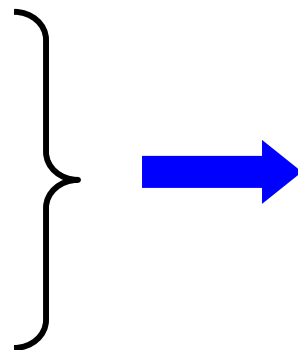
$B_s(3)$: from 2-Track Trigger

Many **fully reconstructed channels**

ONLY @ Tevatron

$$B_s \rightarrow D_s^{(*)-} \pi^+, B_s \rightarrow D_s^{(*)-} 3\pi,$$

$$B_s \rightarrow D_s^{(*)-} D_s^{(*)+}$$



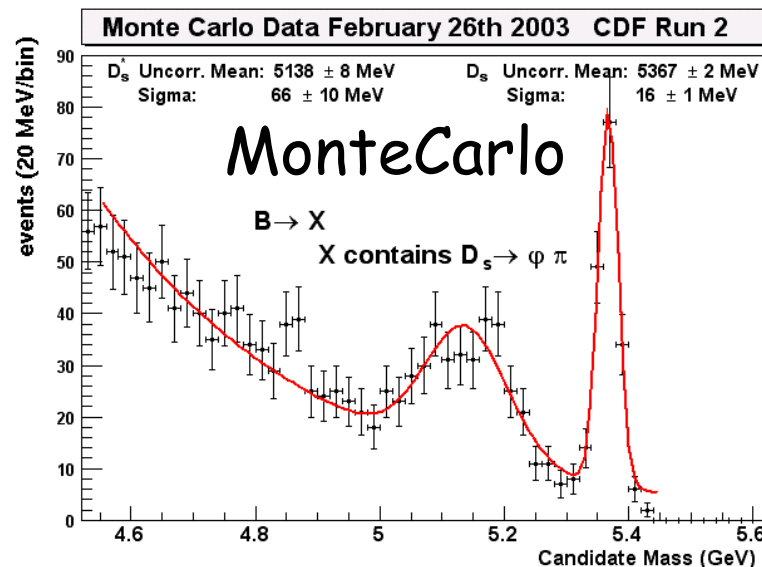
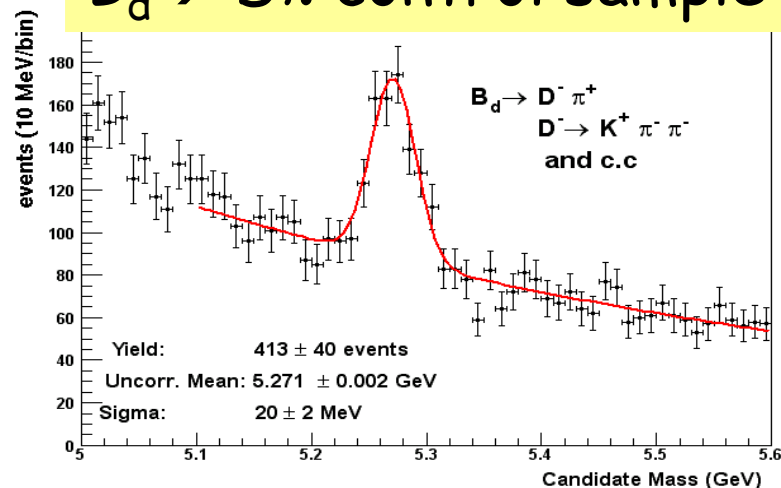
• B_s mixing: "golden sample" for $x_s \rightarrow \Delta M_s$

Needs:

- Excellent proper time resolution
- Good flavour tagging

Combine them to reach high statistics

$B_d \rightarrow D\pi$ control sample



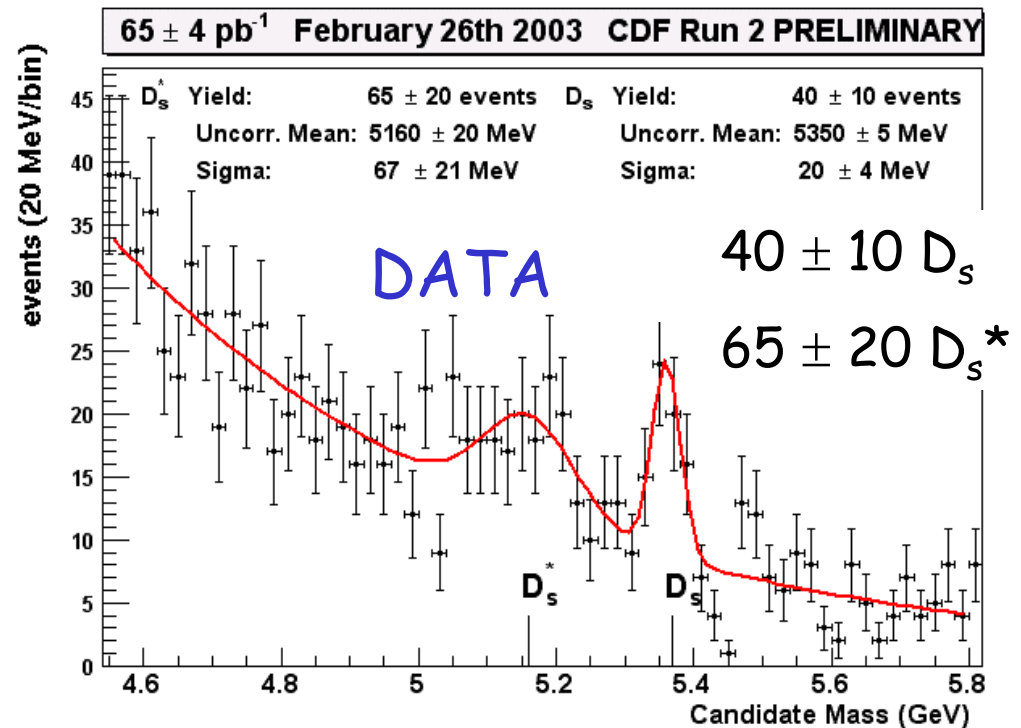
$B_s(3)$: from 2-Track Trigger

$B_s \rightarrow D_s^{(*)} \pi \rightarrow [\phi \pi] \pi \rightarrow [[KK] \pi] \pi$ ONLY @ Tevatron

Fully reconstructed

Promising:

other hadronic
channels to be seen
soon

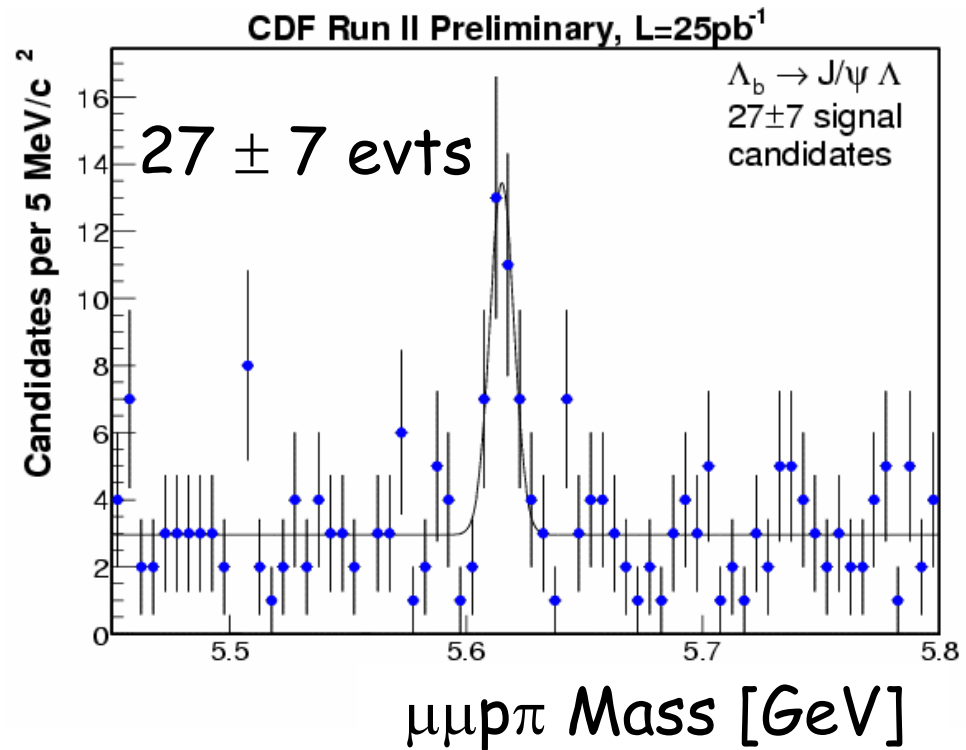


$\Lambda_b(1)$: from di-muon

$\Lambda_b \rightarrow J/\psi \Lambda \rightarrow [\mu\mu][p\pi]$ ONLY @ Tevatron

Fully reconstructed

- Lifetime $\rightarrow \frac{\tau(\Lambda_b)}{\tau(B^0)}$
discrepancy with theory:
is it valid for baryons?
- Mass



$\Lambda_b(2)$: from lepton + displaced track

$$\Lambda_b \rightarrow \Lambda_c l \nu \rightarrow [pK\pi] l \nu$$

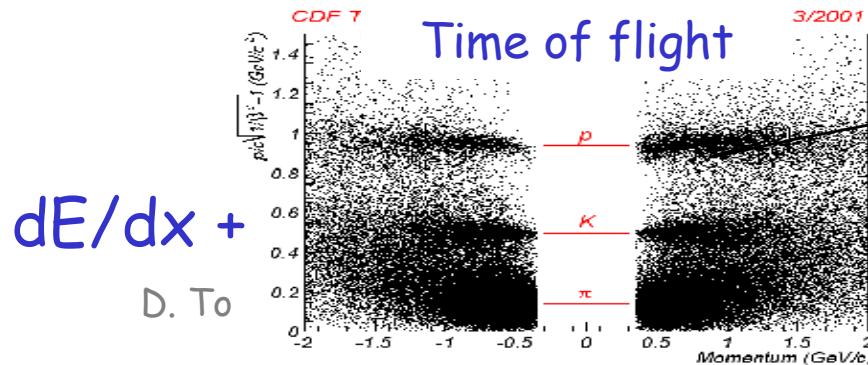
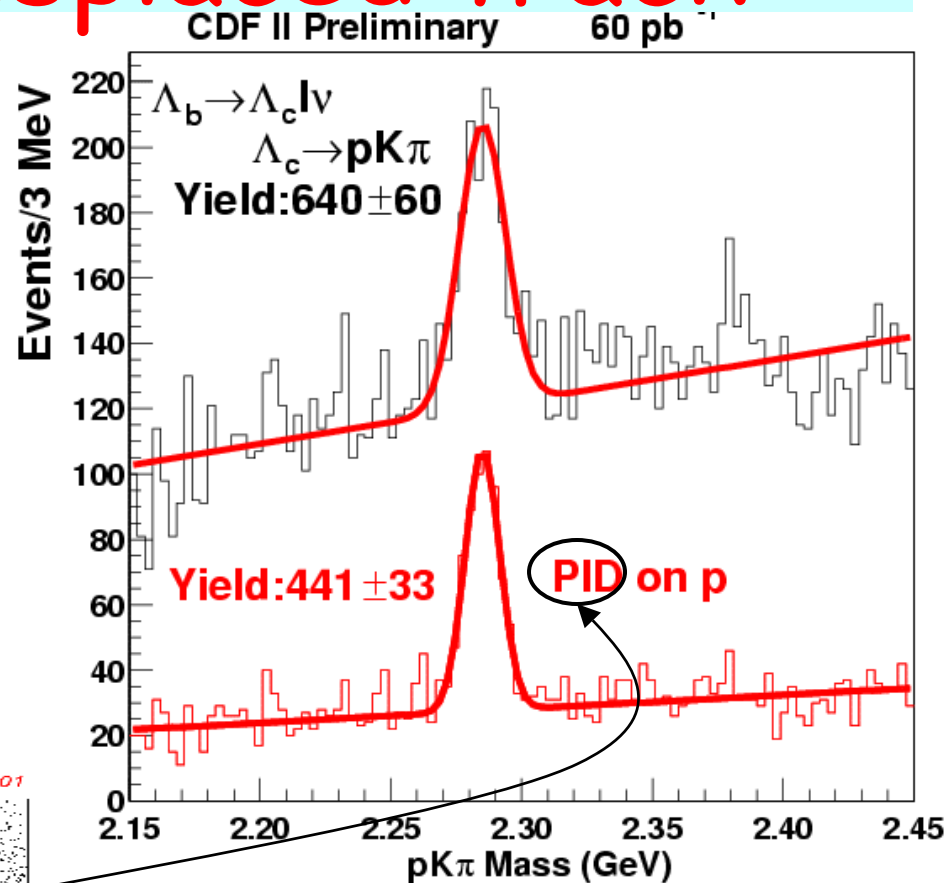
- Branching Ratio
- Measure $\rightarrow \frac{1}{\Gamma} \frac{d\Gamma}{dQ^2}$

$$Q^2 = m(l\nu)$$

important for theory

Experimental challenge:

disentangle from decays through excited baryons



Yield/Lumi = 4 x RunI

S/N ~ 2 x Run I



$\Lambda_b(3)$: from 2-Track trigger

$$\Lambda_b \rightarrow \Lambda_c \pi \rightarrow [pK\pi] \pi$$

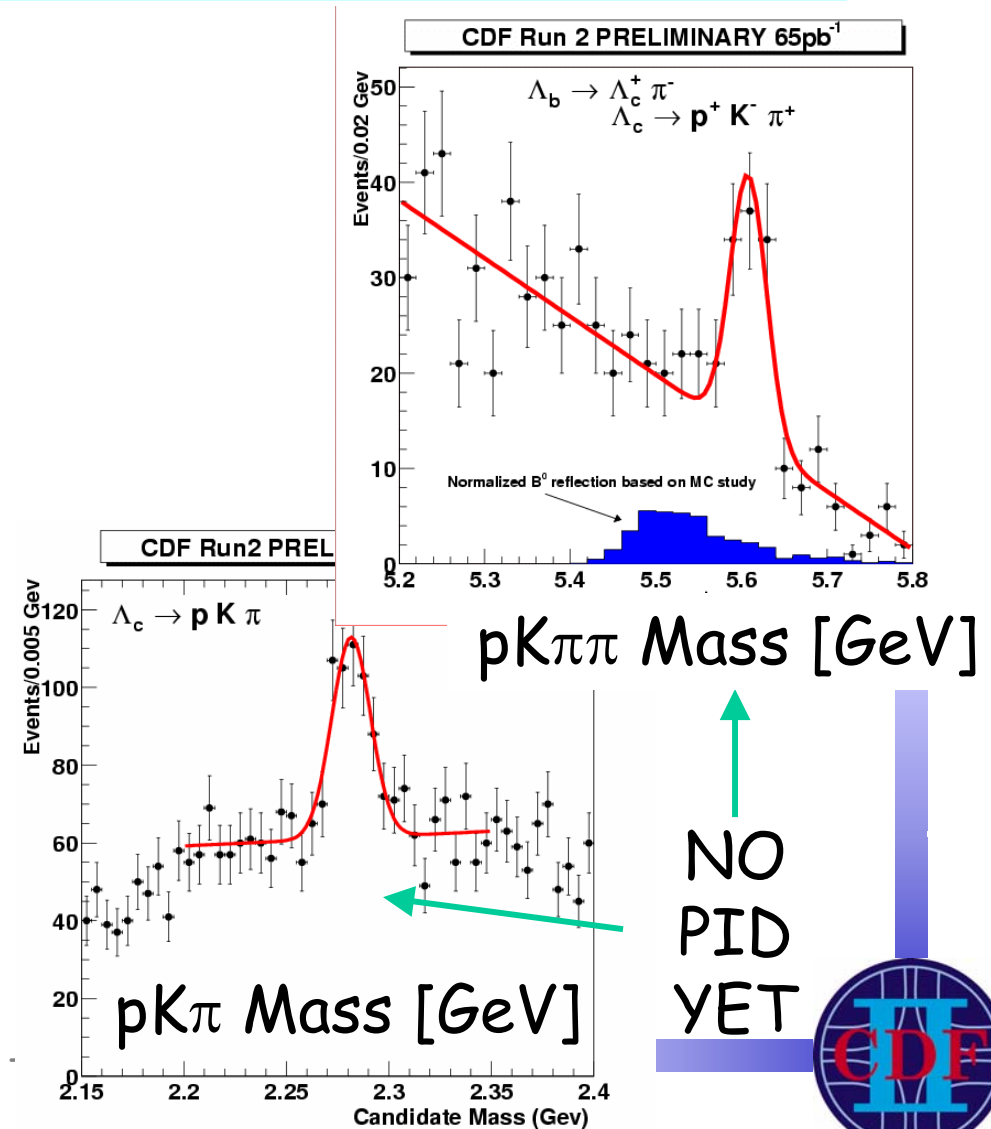
Fully reconstructed channel

→ high resolution on secondary vertex

- Precise Lifetime $\rightarrow \frac{\tau(\Lambda_b)}{\tau(B^0)}$

Discrepancy with theory:
Is it valid for baryons?

- BR still unknown



$B \rightarrow h^+ h^-$ from 2-Track Trigger

$B_d(B_s) \rightarrow K\pi, \pi\pi$ (KK, $K\pi$) **FIRST** charmless B @ hadronic coll.

CP asymmetry $\rightarrow \sin 2(\beta + \gamma)$

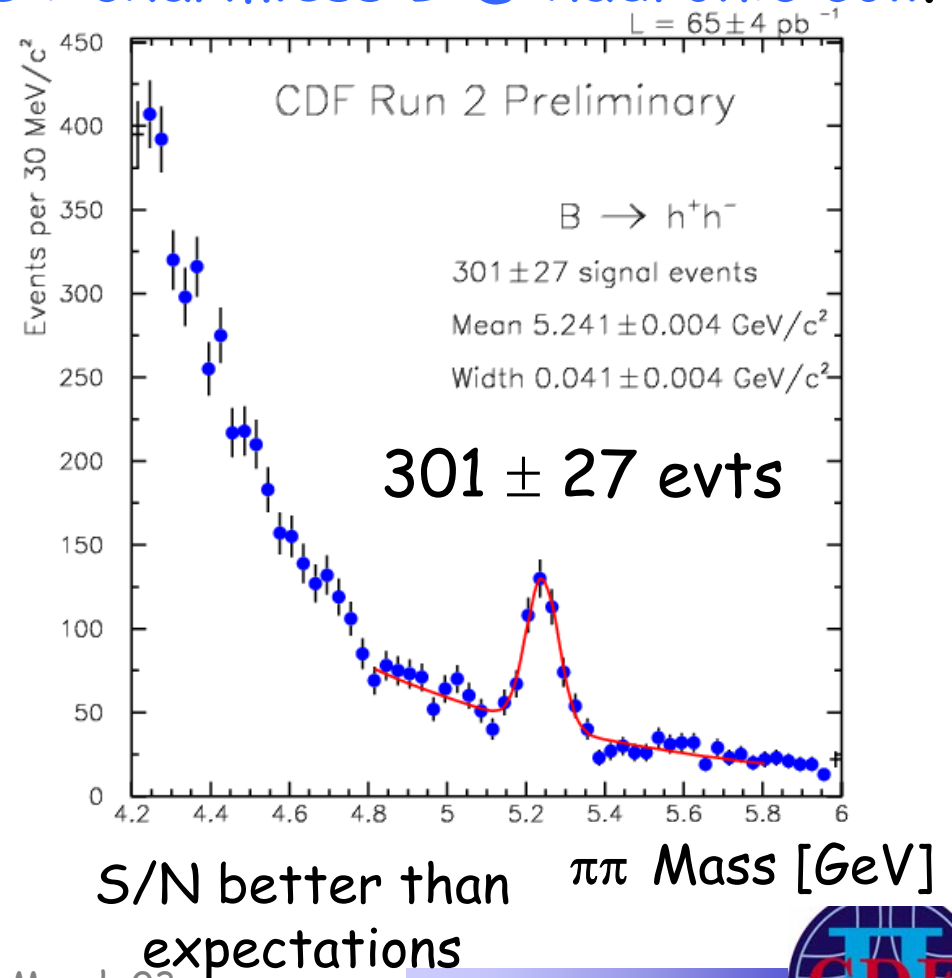
- Time dependent analysis
- Tagging
- Exploit $x_s \gg x_d$

Direct CP violation in $B_d \rightarrow K\pi$

- self-tagging

Extract yield of each individual channel:

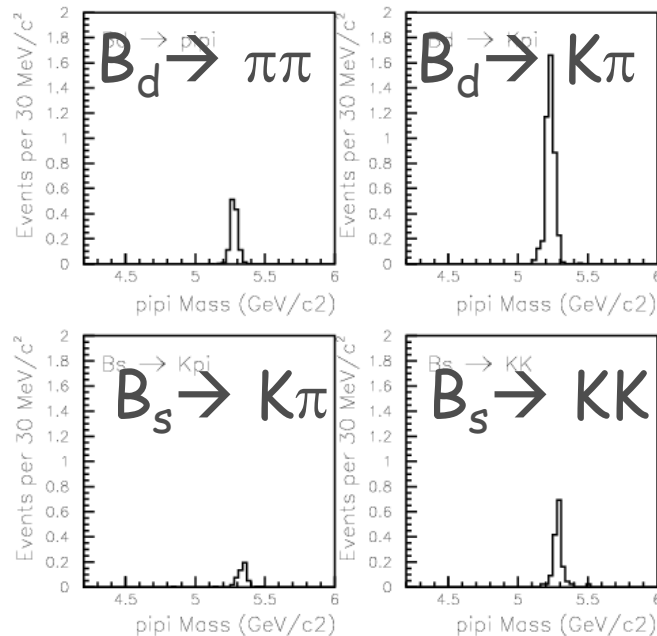
- Branching Ratio $B_s \rightarrow KK/K\pi$



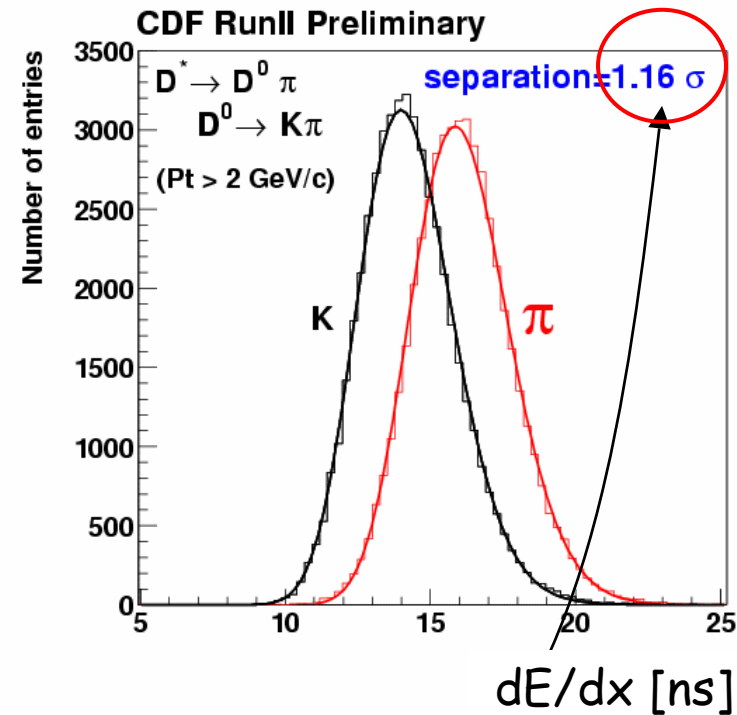
$B \rightarrow h^+ h^-$ from 2-Track Trigger

Experimental challenge:

Disentangle 4 channels:



kinematics + dE/dx



Final resolution
expected is

$$\sigma_{Acp} \sim O(15\%)$$

Summary and Conclusion

CDFII today: the detector is well calibrated, scale of masses and vertexing resolution are accurately understood providing lifetimes and mass measurements already competitive with RunI results.

Promising perspectives for the flagship analyses: tuning of the machinery to study B_s mixing, $\Delta\Gamma_s$, Λ_b , charmless B-decays and many other topics unique to Tevatron is in progress.

CDFII is underway to produce exciting new results



Backup Slides



Luminosity

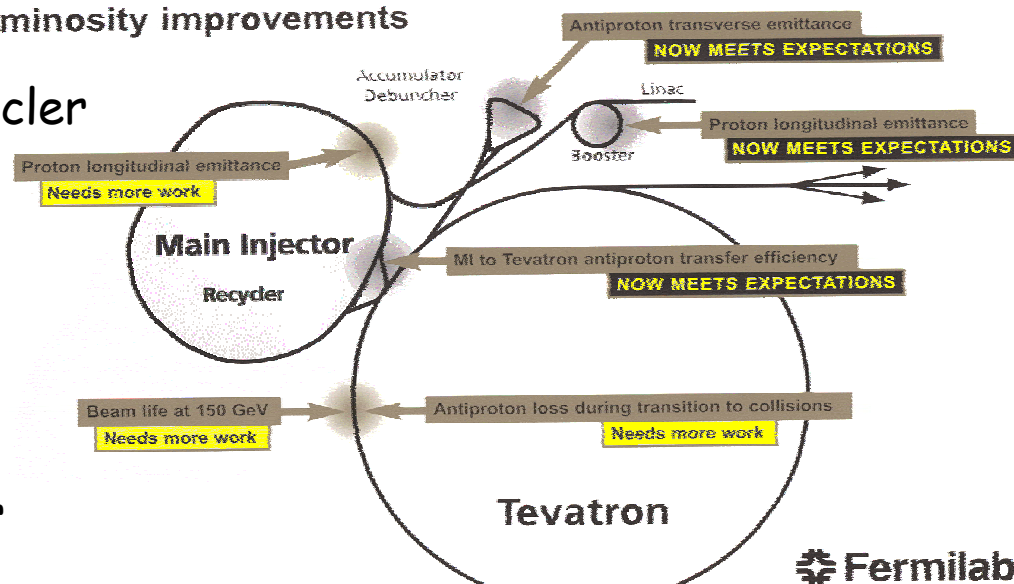
➤ Goals for the RunII:

- $2 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ with Recycler
- 2 fb⁻¹ RunII

➤ Today:

- $3.7 \times 10^{31} \text{ cm}^{-2} \text{ sec}^{-1}$
- 7 pb⁻¹/week
- ~70 pb⁻¹ available for winter conferences

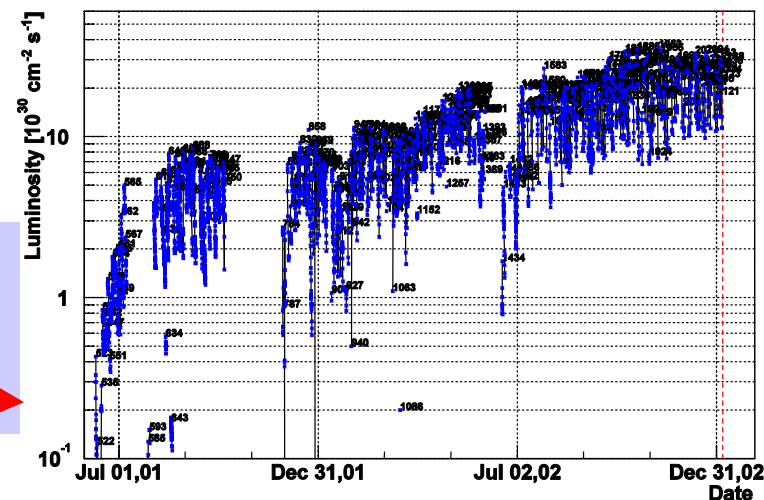
Luminosity improvements



Fermilab

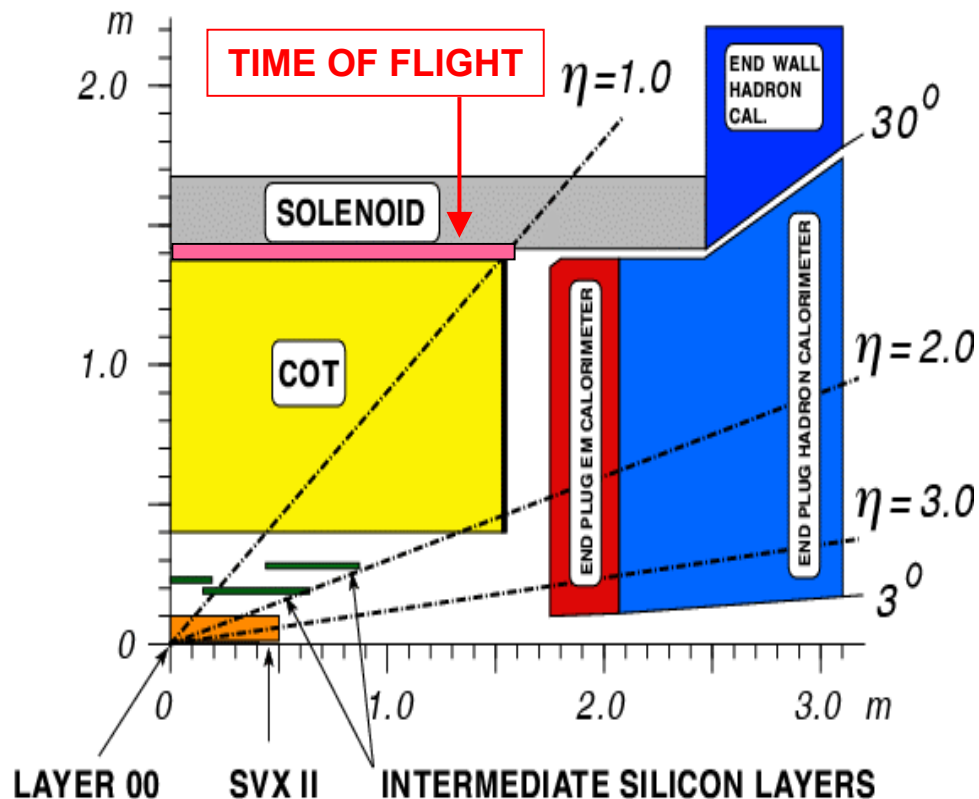
Luminosity with Tevatron store number

Mon Jan 6 12:15:36 2003



Still a factor 1.3÷2 below expectations,
but constantly in progress
~×5 during 2002

Quadrant of CDF II Tracker



TOF: 100ps resolution, 2 sigma K/ π separation for tracks below 1.6 GeV/c (significant improvement of B_s flavor tag effectiveness)

COT: large radius (1.4 m) Drift C.

- 96 layers, 100ns drift time
- Precise P_T above 400 MeV/c
- Precise 3D tracking in $|\eta| < 1$

$\sigma(1/P_T) \sim 0.1\% \text{GeV}^{-1}$; $\sigma(\text{hit}) \sim 150 \mu\text{m}$

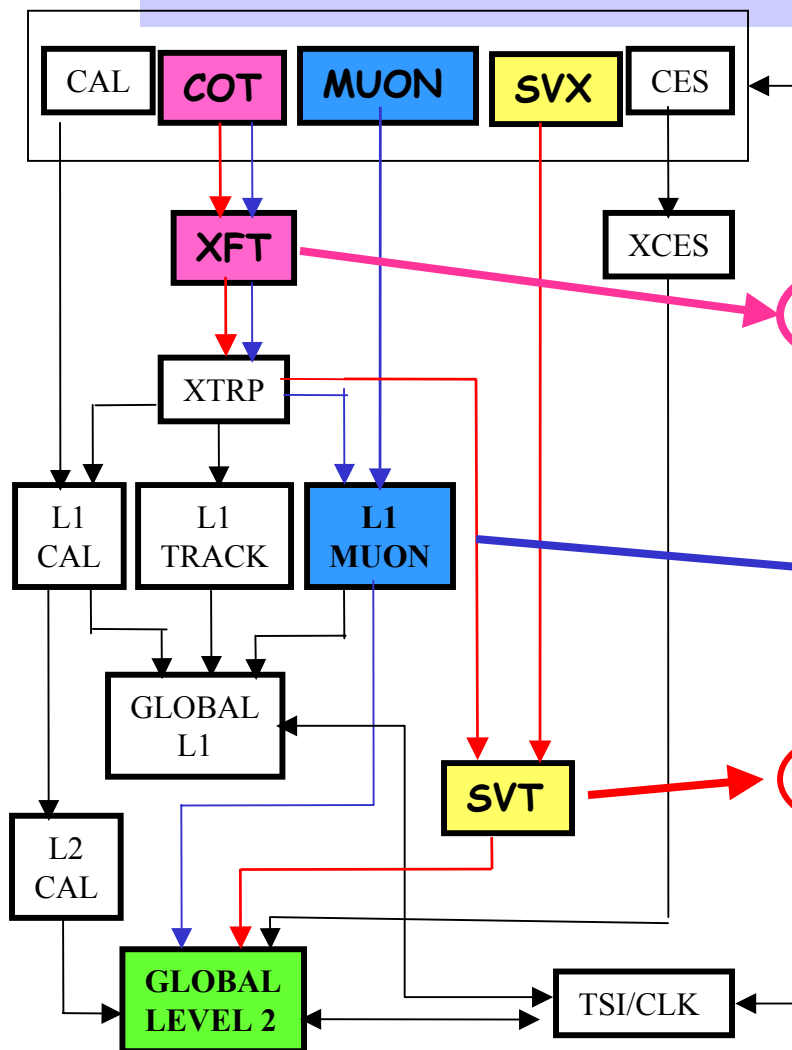
- dE/dx info provides 1 sigma K/ π separation above 2 GeV

SVX-II + ISL: 6 (7) layers of double-side silicon ($3\text{cm} < R < 30\text{cm}$)

- Standalone 3D tracking up to $|\eta| = 2$
- Very good I.P. resolution: $\sim 30 \mu\text{m}$ ($\sim 20 \mu\text{m}$ with Layer00)

LAYER 00: 1 layer of radiation-hard silicon at very small radius (1.5 cm)
(achievable: 45 fs proper time resolution in $B_s \rightarrow D_s \pi$)

CDFII Trigger system



3 levels : 5 MHz (pp rate)

→ 50 Hz (disk/tape storage rate)
almost no dead time (< 10%)

XFT: "EXtremely Fast Tracker"

2D COT track reconstruction at Level 1

- P_T res. $\Delta p_T/p_T^2 = 2\%$ (GeV^{-1})
- azimuthal angle res. $\Delta\phi = 8$ mrad

Matched to L1 ele. and muons

➡ enhanced J/ψ samples

SVT: "Silicon Vertex Tracker"

precise 2D Silicon+XFT tracking at Level 2

- impact parameter res. $\sigma_d = 35$ μm

Offline accuracy !!

Trigger on displaced vertices

Typical $\beta\gamma c\tau$ for B hadrons :

$$\sim 2 \times 370 \div 500 \text{ } \mu\text{m} \sim 0.5 \div 1 \text{ mm}$$

- ❖ Typical resolution on **IP** "impact parameter" with silicon vertex detector is:

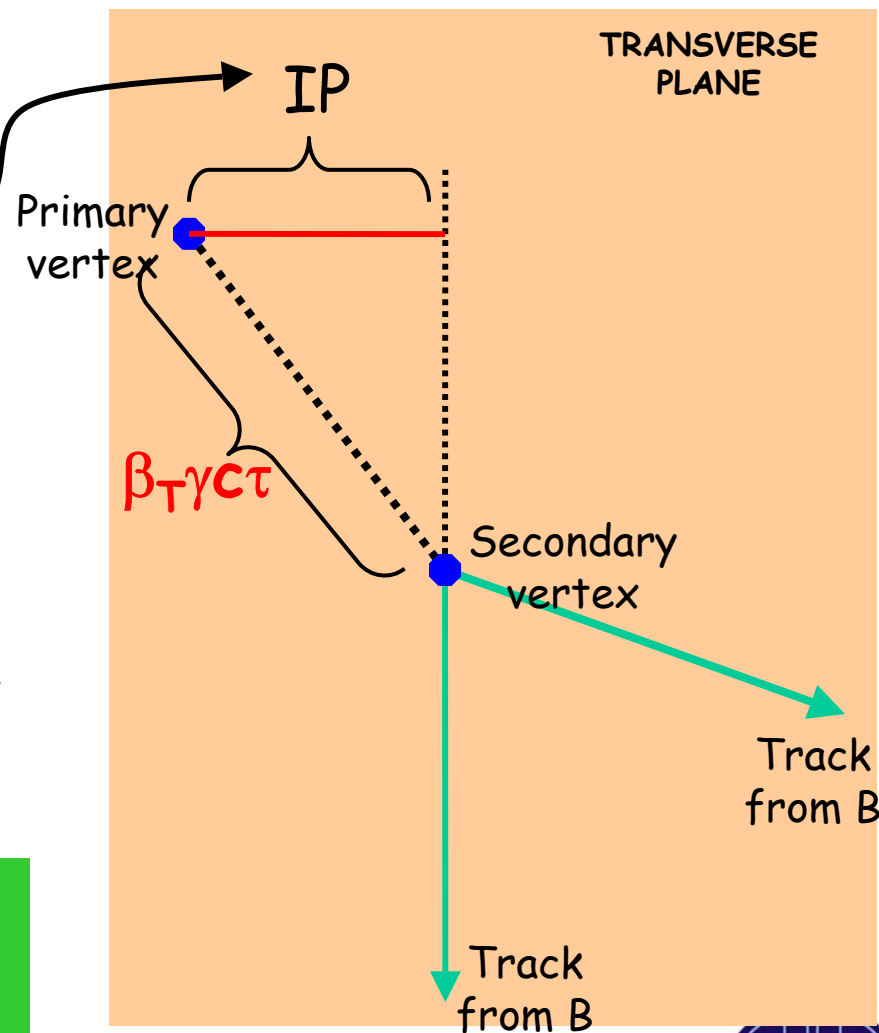
$$\sigma_{\text{IP}} = 30 \text{ } \mu\text{m} \otimes \text{Beam Spot} \cong 50 \text{ } \mu\text{m}$$



- ✘ IP discriminates B from background :
 - ❖ $\text{IP}(\text{B tracks}) \gg \text{IP}(\text{BG tracks})$
- ❖ Available at second Level of Trigger

2D Si tracks within $20\mu\text{s}$

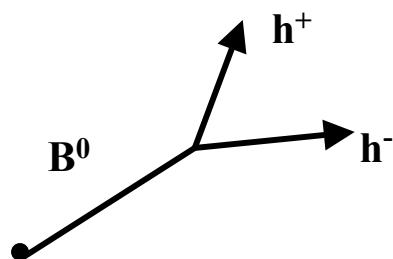
Online, deadtimeless



Hadronic Triggers

Level 1: 2 XFT tracks
 $P_T > 2 \text{ GeV}$
 $\Delta\phi < 135^\circ$
 $P_{T1} + P_{T2} > 5.5$

“Two body decays”



$B^0 \rightarrow \pi \pi$
 $B^0 \rightarrow K \pi$
 $B_s \rightarrow K K$
 $B_s \rightarrow \pi K$
 $\Lambda_b \rightarrow p \pi(K)$

Level 2

1/100

$d > 100 \mu\text{m}$
 $20^\circ < \Delta\phi < 135^\circ$
 $L_{xy} \geq 200 \mu\text{m}$
 $d_B < 140 \mu\text{m}$

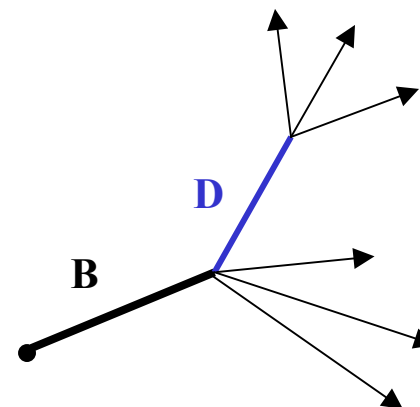
$d > 120 \mu\text{m}$
 $2^\circ < \Delta\phi < 90^\circ$
 $L_{xy} \geq 200 \mu\text{m}$

1/1000

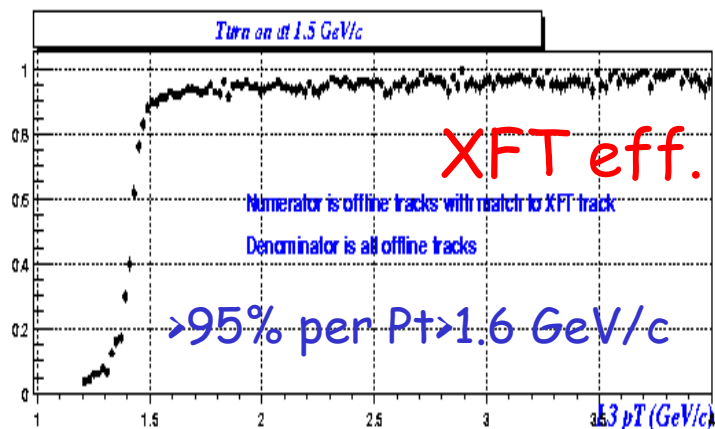
Level 3

SAME with refined tracks
 & Mass cuts

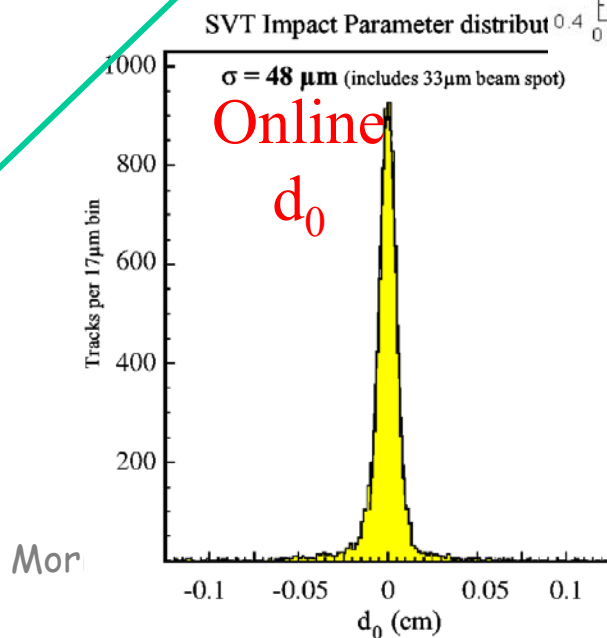
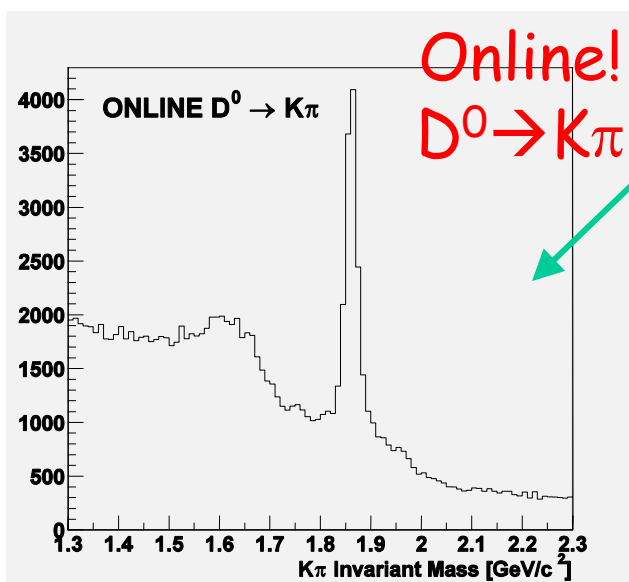
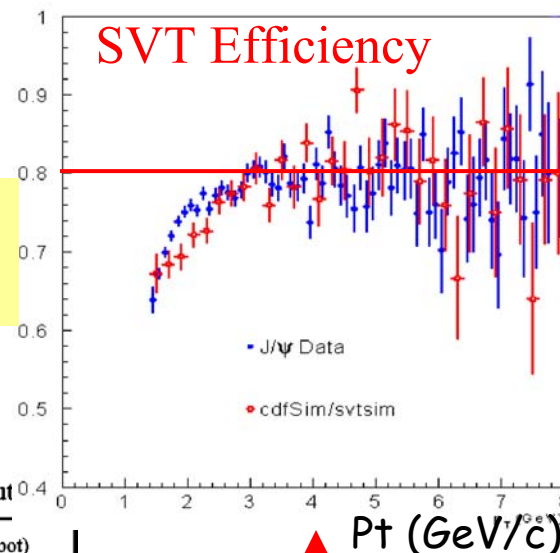
“Multi-body decays”



Trigger (XFT+SVT): Performance today ...



~ 5 hrs @ 4×10^{31}
 ~ 1 hr @ 2×10^{32}

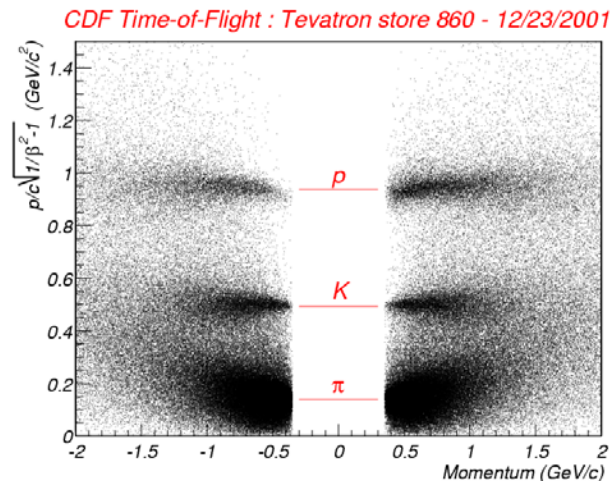


Today $\sim 90\%$

$\sigma = 48 \mu\text{m}$



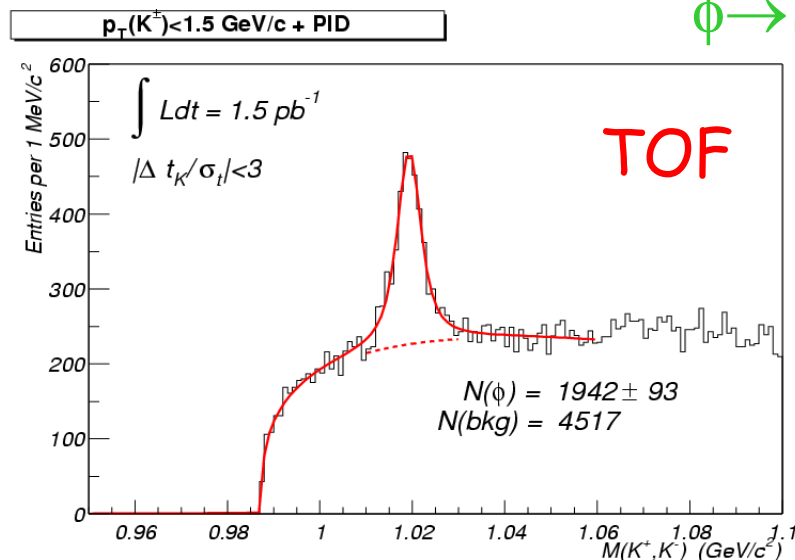
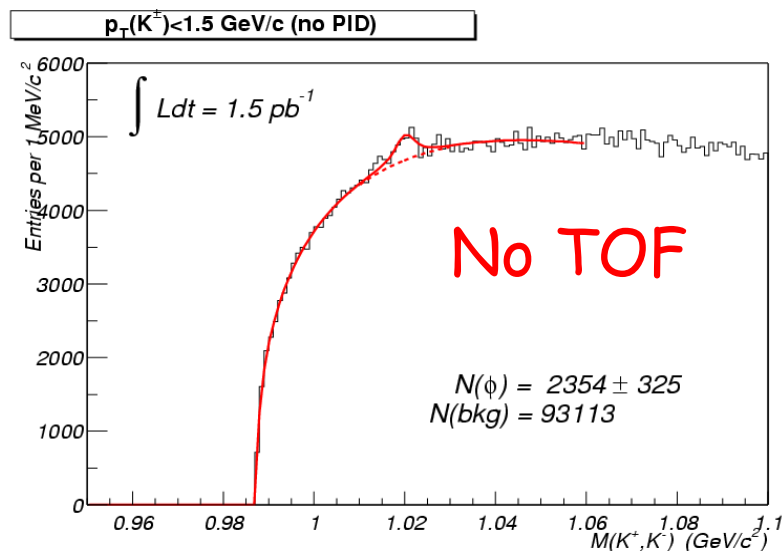
TOF: performance today ...



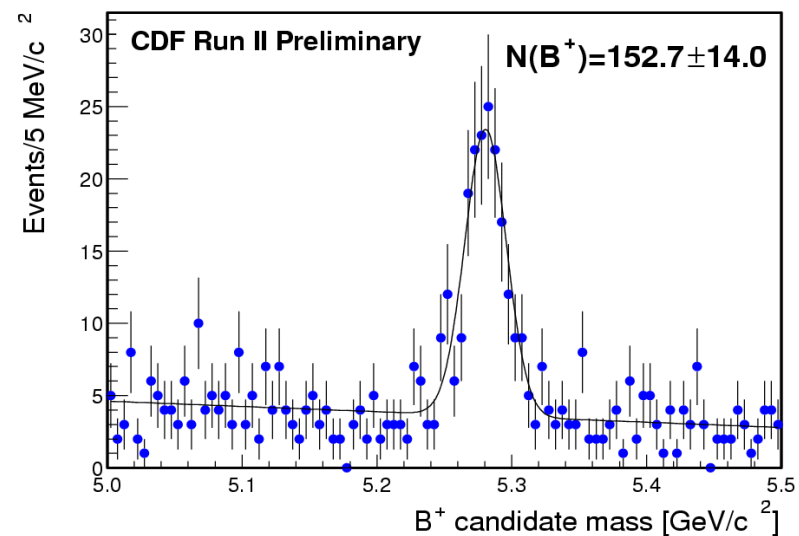
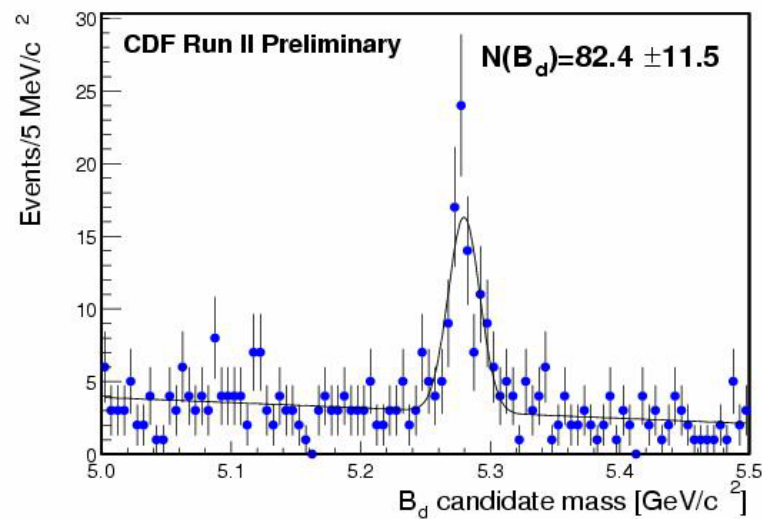
Resolution ~ 120 ps (first calibration round)
Already useful for PID

Reconstructed mass VS p

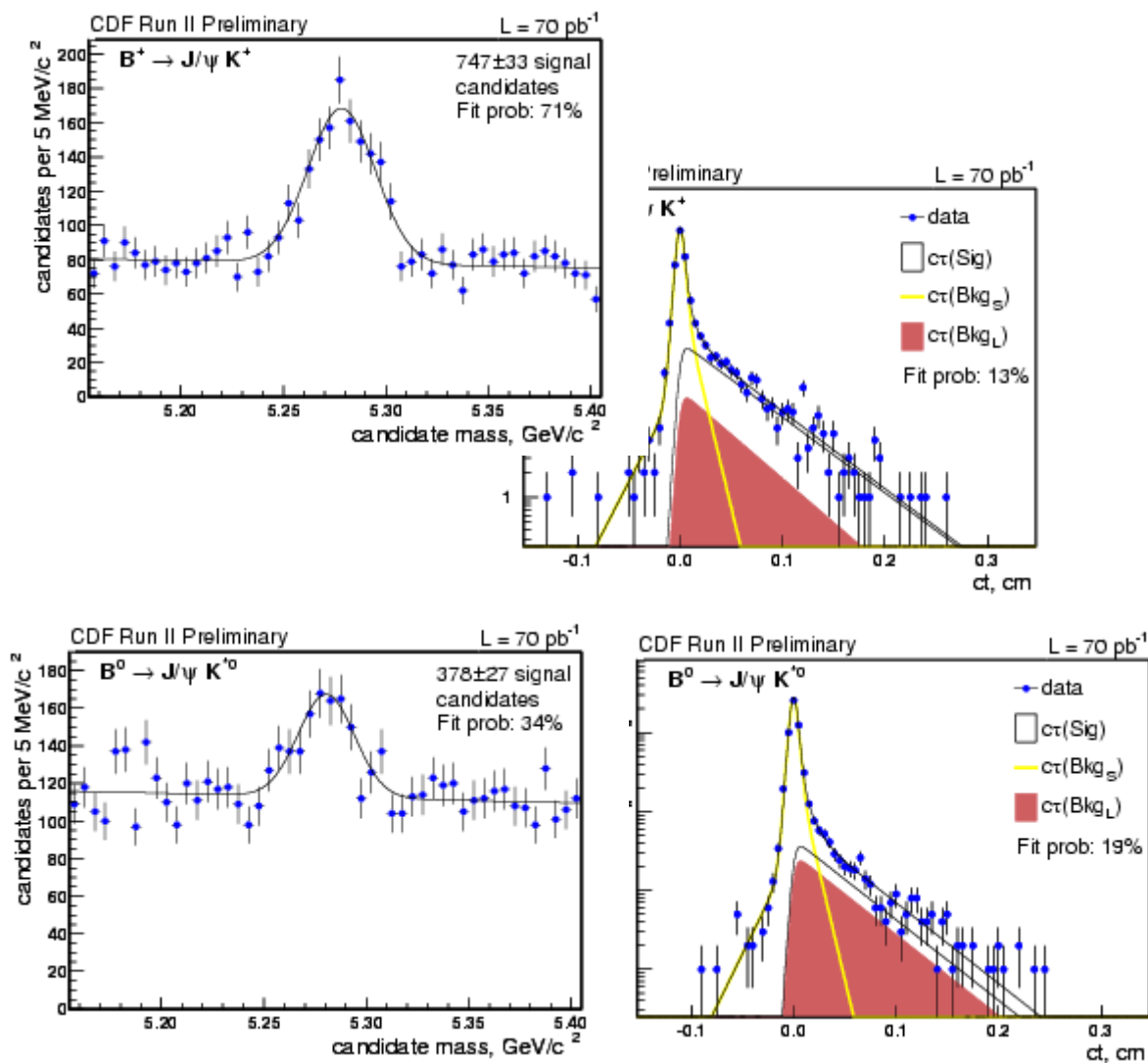
BG reduction $\times 20$ @ 80% eff.



Masses



Lifetimes



Di-muon : $\sin(2\beta)$

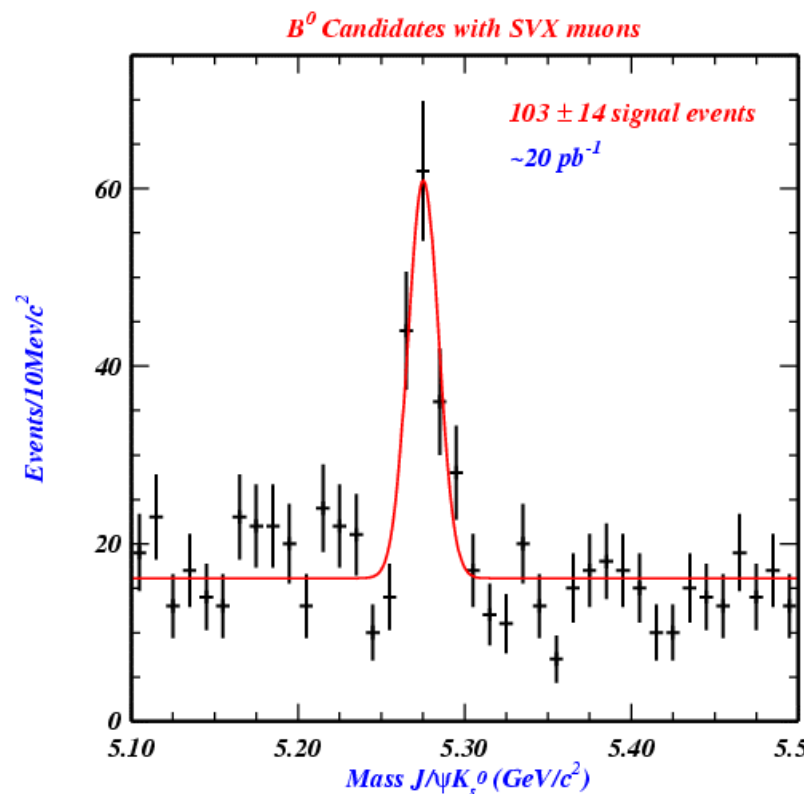
$$B_d \rightarrow J/\psi K_s \rightarrow [\mu\mu] K_s$$

Benchmark of B physics
performance of detector:

$\sin(2\beta)$ analysis uses all experimental
ingredients and RunI cross-check:

- Reconstruction (Vertexing)
- Time dependent Asymmetry
- Flavor Tagging (dominates in error)

$$\text{Yield} = \text{RunI} \times 5$$

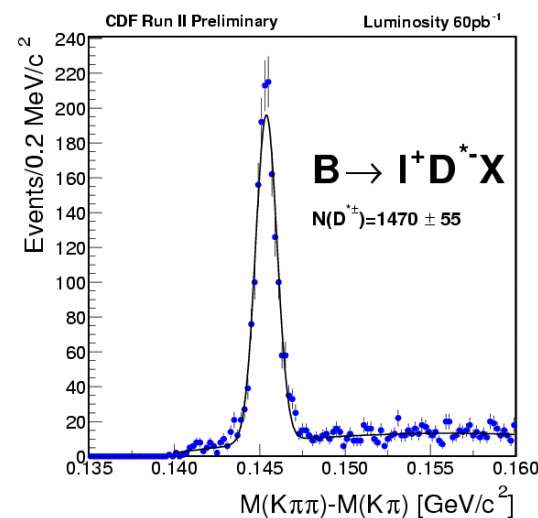
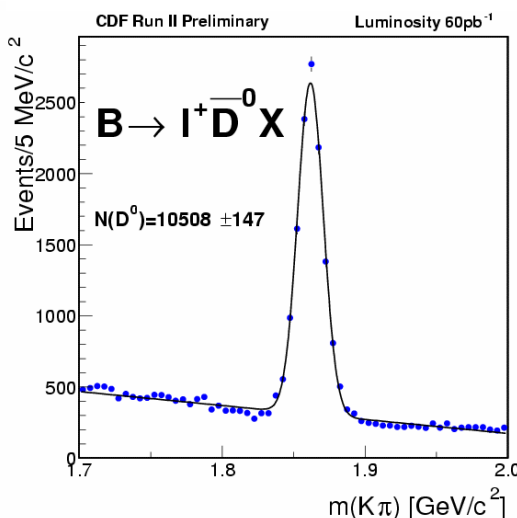
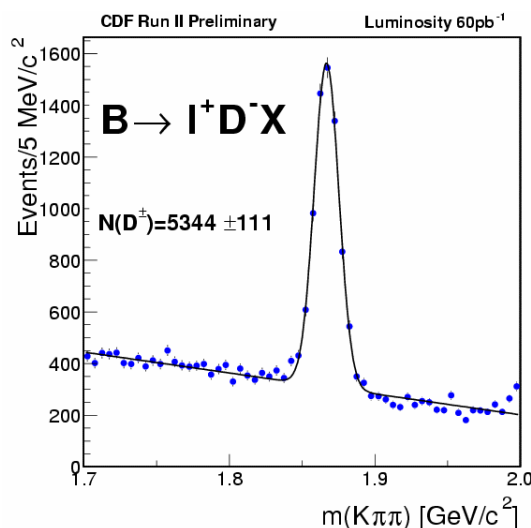


Displaced track + lepton (1) : semileptonic B

High statistics, excellent S/N ratio wrt to RunI:

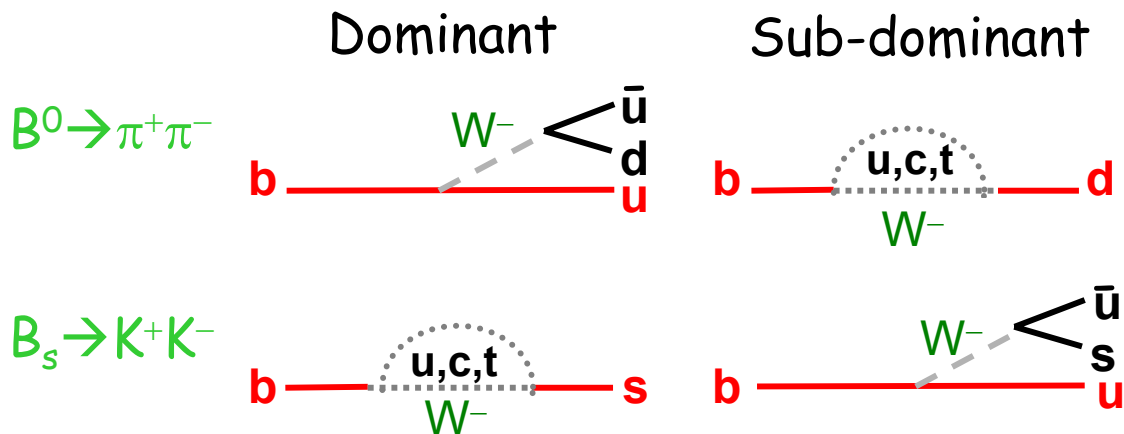
Signal yield \sim RunI \times 5 , S/N \sim RunI \times 2

Mass, lifetimes x-check and use this sample to measure effective dilution of tagging algorithms



γ via $B^0 \rightarrow \pi^+ \pi^-$ / $B_s \rightarrow K^+ K^-$

- CDF not “optimized” to measure final states with π^0, γ
 - Measurement of α in $B \rightarrow h^+ h^-$ not competitive with B-factories
- Promising alternative approach (R.Fleischer):
 - $B^0 \rightarrow \pi^+ \pi^-$ measures $\sin 2(\beta + \gamma)$ with $O(30\%)$ penguin pollution
 - Contamination is canceled using $B_s \rightarrow K^+ K^-$ up to U-spin symmetry breaking $O(20\%)$



$$A_{CP}(t) = A_{CP}^{dir} \times \cos \Delta M t + A_{CP}^{mix} \times \sin \Delta M t$$

$$A_{CP}^{dir}(\pi\pi) = -2d \sin \theta \sin \gamma + O(d^2)$$

$$A_{CP}^{dir}(KK) = \frac{2\lambda^2}{d(1-\lambda^2)} \sin \theta \sin \gamma + O((\lambda^2/d)^2)$$

$$A_{CP}^{mix}(KK) = \frac{2\lambda^2}{d(1-\lambda^2)} \cos \theta \sin \gamma + O((\lambda^2/d)^2)$$

$$A_{CP}^{mix}(\pi\pi) = \sin 2(\beta + \gamma) + 2d \cos \theta \times [\cos \gamma \sin 2(\beta + \gamma) - \sin(2\beta + \gamma)] + O(d^2)$$

Decays related by exchange $d \leftrightarrow s$ ($SU(3)$ U-spin)

- Measurement of the 4 time-dependent asymmetries
- Combined fit to the 4 experimental observables ($\sin(2\beta)$ from $J/\psi K_s$):
- $d = P/T \sim 0.3$, θ = strong phase of the ratio P/T , γ, β weak phases



B flavour tagging

"Identify the flavor of B at production"

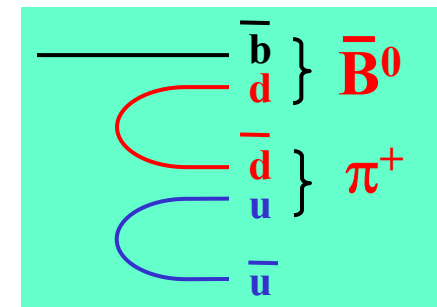
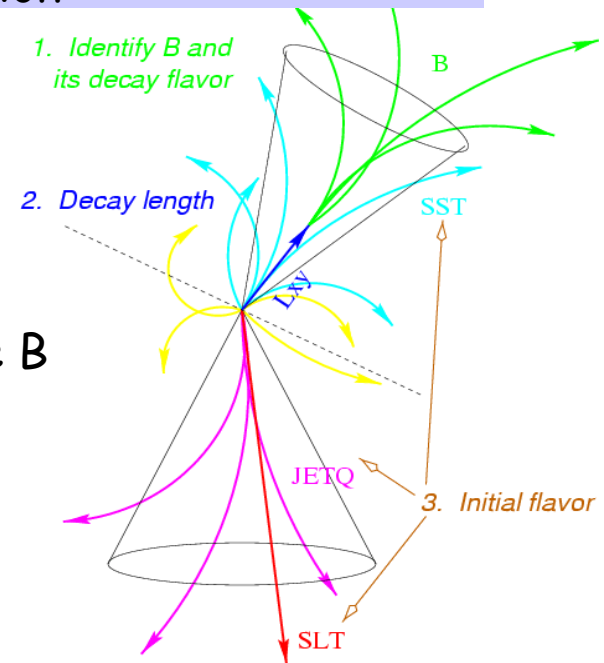
Crucial item for mixing measurements

OST (opposite side tagging):

B's are produced in pairs \rightarrow measure flavor of opposite B

➤ **JETQ**: sign of the weighted average charge of opposite B-Jet

➤ **SLT**: identify the soft lepton from semileptonic decay of opposite B



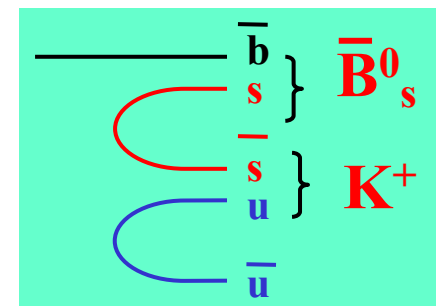
SST (same side tagging):

\bar{B}^0 (B^0) is likely to be accompanied close by a π^+ (π^-)

➤ Search for the track with minimum P_T^{REL}

NEW: "Kaon b-taggers"

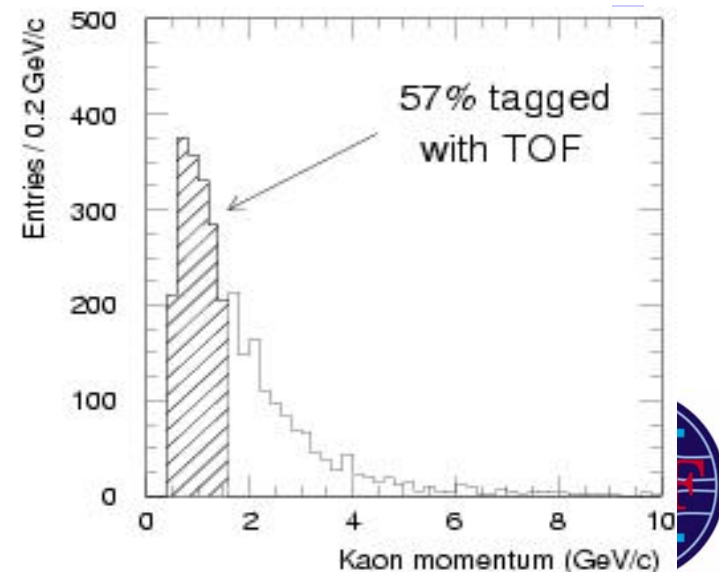
- Exploit K/π separation of new TOF
- Well suited for strange B mesons



Same Side K: a \bar{B}^0_s (B^0_s) is likely to be accompanied close by a K^+ (K^-) from fragmentation

Opposite Side K: due to $b \rightarrow c \rightarrow s$ it is more likely that a B meson will contain in final state a K^- than a K^+

\Rightarrow to identify a B^0_s look for a K^- from the decay of the opposite B



B Flavor tagging in CDF

Total Tagging Effectiveness

ϵD^2 (%)	RunI	RunII	
		B^0	B_s
OS Soft Lept	1.7	1.7	1.7
OS Jet Charge	3.0	3.0	3.0
OS Kaon		2.4 (0)	2.4 (0)
SST	1.0	1.9 (1.4)	
SST Kaon			4.2 (1.0)
Total	5.7	9.0 (6.3)	11.3 (5.7)

ϵ : efficiency

How many times it is possible to apply the tag

$D = (1-2P_w)$: dilution

How many times the tag is wrong

ϵD^2 : determines the effective statistics of the sample:

$$S \rightarrow \epsilon D^2 S$$

$$A_{\text{mis}} = DA \quad \delta A \propto \frac{1}{\sqrt{\epsilon D^2 S}}$$

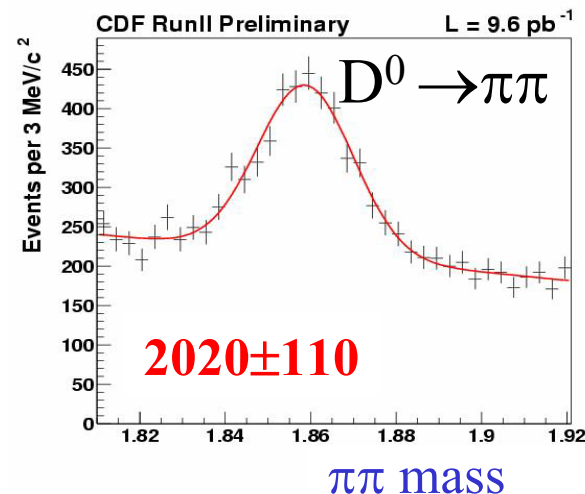
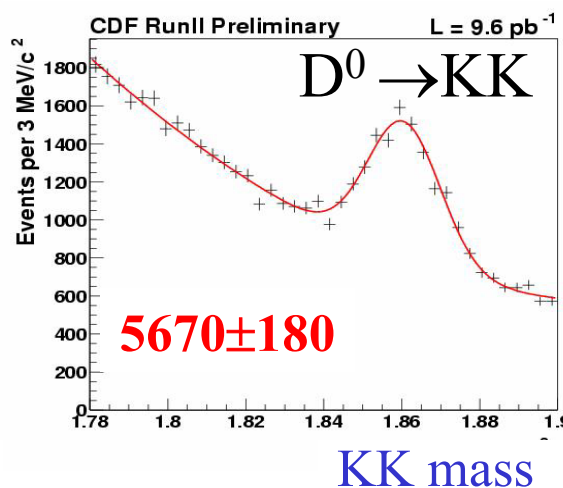
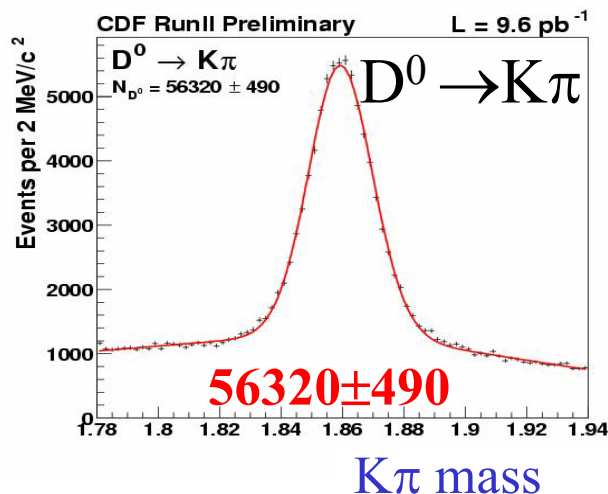
*Without TOF

- Through identification of π , K (e p) the TOF allows ~doubling ϵD^2 for B^0 and B_s



Lots of Charm from hadr. triggers:

With $\sim 10 \text{ pb}^{-1}$ of "hadronic trigger" data:



Relative BR of Cabibbo-suppressed D^0 decays :

$$\begin{aligned} \Gamma(D \rightarrow KK) / \Gamma(D \rightarrow K\pi) &= 11.17 \pm 0.48 \pm 0.98 \text{ (syst) } \% \\ \Gamma(D \rightarrow \pi\pi) / \Gamma(D \rightarrow K\pi) &= 3.37 \pm 0.20 \pm 0.16 \text{ (syst) } \% \end{aligned}$$

Already competitive
with CLEO2 results
(10fb-1 @ Y(4S))

$O(10^7)$ fully reconstructed decays in 2fb-1

⇒ Foresee a quite interesting charm physics program:

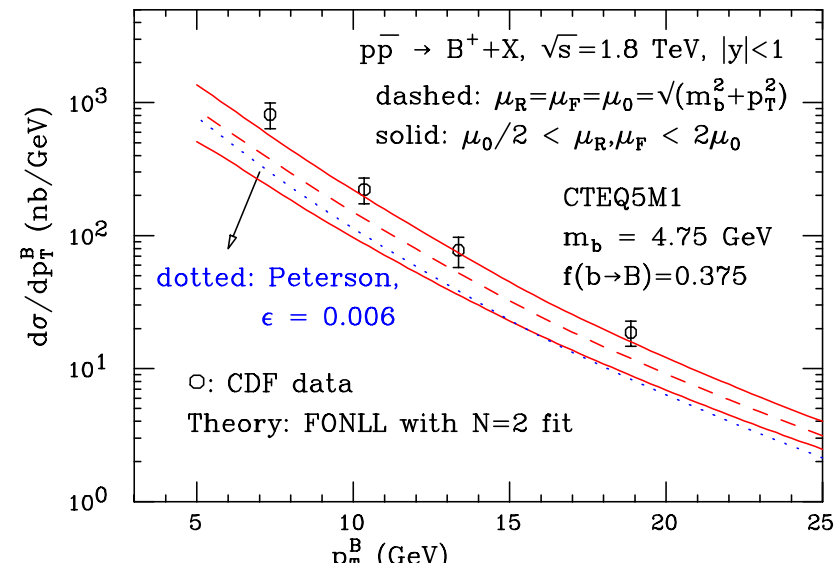
- D cross sections,
- CP asymmetries and Mixing in D sector, Rare decays, ...



Production

- Wide production of all B hadron species →
Tevatron ideal environment to study production mechanisms
- X-section $pp \rightarrow B+X$ measured in RunI is a factor 1.7 above QCD expectations
- Rich event sample will allow precise test of the observed effect.

... possible explanation (Cacciari/Nason)



- High statistics + improved acceptance
→ precision measurements of the correlations in bb production (separation of various production mechanisms)

